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Air Products

Air Products and Chemicals, Inc.

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AD A140498

20 January 1984

Director, Advanced Research
Projects Agency
1400 Wilson Boulevard
Arlington, VA 22209

Attention: Program Management

Gentlemen:

SUBJECT: Contract N00014-83-C-0394
Item No. 0002 Data
Sub-Item A001 R&D Status Report #2

Attached is R&D Status Report #2 for the subject contract covering the period from 1 October 1983 to 31 December 1983. A request to change the effective date of the contract to 1 October 1983 has been submitted separately.

Very truly yours,

Ralph C. Longsworth

Ralph C. Longsworth
Program Manager

sk

cc: Scientific Officer
DCASMA - Reading, Pa.
Director, Naval Research Laboratory
Defense Technical Information Center

Enclosures

Air Products

R&D STATUS REPORT

DARPA ORDER NO.: 4746 PROGRAM CODE NO.: --

CONTRACTOR: Air Products and Chemicals, Inc.

CONTRACT NO.: N00014-83-C-0394 CONTRACT AMOUNT: $594,000

EFFECTIVE DATE OF CONTRACT: '83 July 01

EXPIRATION OF CONTRACT: '85 June 30

PRINCIPAL INVESTIGATOR: W. A. Steyert PHONE NO.: (215) 481-3700

PROGRAM MANAGER: R. C. Longsworth PHONE NO.: (215) 481-3708

SHORT TITLE OF WORK: Solid State Compressor

REPORTING PERIOD: '83 July 01 - '83 September 30 cover

- PROGRESS:

  Progress Report is attached.

- KEY PERSONNEL: No changes

- SPECIAL EVENTS: None

- PROBLEMS ENCOUNTERED AND/OR ANTICIPATED: None

- ACTION REQUIRED BY THE GOVERNMENT:

  A request to change the effective date of the contract from '83 July 01 to '83 October 01 has been made under separate cover.

- FISCAL STATUS:

  (1) Amount currently provided on contract: $175,000

  (2) Expenditure and commitments to date: Per separate report

  (3) Funds required to complete work: Per contract

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PROGRESS REPORT

1.0 SUBCONTRACTS

Subcontracts were mailed to CeramPhysics and Penn State University. They should be signed off in early January. The work reported herein was performed by Air Products and Chemicals, Inc.

2.0 TASK 2. MECHANICAL SIMULATOR: SUBTASK 2.1, ONE CELL SIMULATOR

2.1 Purpose

The overall goal of this program is to develop a gas compressor which uses modern piezoelectric or electrostrictive materials in place of a magnetic type motor. These materials can exert very large forces, but have only a limited travel. The key to the successful implementation of this compressor concept is a motion amplifier which will be studied at APCI in a one cell simulator. Prior to building the simulator which will be used primarily to study material properties, we have analyzed the elastomer requirements.

The motion amplifier is an elastomer which is squeezed between two plates, ~~as shown in Figure 1(a).~~ The elastomer is basically incompressible; therefore, as the plates move together the elastomer will extrude from around the edges. Figure 1(b) shows the elastomer extruding into a gas space surrounding the elastomer and compressing the gas in the space.

It is necessary to understand the mechanics of the elastomer motion in order to design the motion amplifier and, thus, the compressor. Therefore, the first experiments have been designed to try to understand the elastomer when used in this way.

2.2 Method

Elastomer samples were placed between two brass disks. The disks were pressed together by a pneumatically driven ram. The motion of the disks as a function of ram pressure was observed for several elastomers and for 1" and 1/2" disk diameters. The elastomers were characterized by measurements of their durometer (the standard measure of elastomer hardness) and their Young's modulus. In addition, the elastomers were pressed between disks which had a smooth finish, a rough finish, and where the elastomer was actually glued to the surface of the disks.

The force versus disk displacement was compared to estimates based on the theory of elastomeric materials.

2.3 Expected Elastomeric Behavior

Figure 2(a) shows two plates with an elastomer bonded between them. When the plates are subjected to the force shown in Figure 2(b) the elastomer is placed under shear. If we neglect possible small changes in w associated with the shear force we have

$$F = hLG\ (dy/dx) \tag{1}$$

$$= hLG\ (Y/w) \tag{2}$$

where h is the height of the plate, L is its length, G is the modulus of elasticity in shear or the modulus of rigidity and dy/dx is the shear strain which in this case is uniform throughout the elastomer.

It can be shown that

$$G = E/2\ (1 + \nu) \tag{3}$$

where E is the modulus of elasticity in tension on the Young's modulus and ν is the Poisson's ratio for the material. We find that ν is near to 1/2 for elastomers, which is to say that forces which are sufficient to change its shape do not cause an appreciable change in volume; from Reference 1 we have

$$e = -3\ (1-2\ \nu)\ P/E \tag{4}$$

where e is the volume change, when a material is subjected to a hydrostatic pressure, P.

Next, consider the elastomer of Figure 2(a) to be subjected to a pressure, P as shown in Figure 2(c). Equation 1 is still applicable, except that now F and dy/dx are functions of x. The upward force on the section of elastomer between -x and x (Figure 2(d)) is 2 xLP. Hence, the elastomer must supply a downward (negative force)

$$F(x) = -2xLP = 2Lh\ dy/dx\ G \tag{5}$$

solving and setting $y = 0$ at $x = \pm\ w/2$ we have

$$y = \left[(w/2)^2 - x^2\right] P/2Gh \tag{6}$$

The maximum y, at x = 0, is

$$y_{max} = w^2 P/8Gh \tag{7}$$

A simple integration of Equation 6 shows that the average y between -w/2 and w/2 is (2/3) y_{max} .

How much energy, Q, have we put into the elastomer by applying pressure, P?

$$Q = 1/2\ \left[(2/3)\ y_{max}\ wL\right] P \tag{8}$$

$$= (8/3)\ y_{max}^2\ LhG/w \tag{9}$$

where we have taken $Q = 1/2\ \Delta VP$ where P is the final pressure and ΔV is the final volume of gas expansion below the elastomer in Figure 2(c) associated with the application of the pressure.

Let us apply a pressure P to the plates as shown in Figure 2(e). They will move together a distance δ and the rubber will extrude a distance y_{max}. Volume conservation gives

$$(2/3\ y_{max})\ (w)\ L = Lh\delta \tag{10}$$

or y_{max} and δ are related by

$$y_{max} = (3/2)\ h\delta/w \tag{11}$$

Let us equate the energy in the elastomer to the energy supplied by moving the plates a distance δ; from Equation 9

$$Q = (1/2)\ \delta\ PLh = (1/3)\ (8/3\ y^2_{max}\ LhG/w) \tag{12}$$

where the factor of 1/3 relates the average value of the strain energy, (proportional to y^2) to the maximum strain energy at the top of the plate.

Combining Equations 11 and 12 we get

$$P = 4h^2\delta G/w^3 \tag{13}$$

This describes the pressure required to squeeze an elastomer an amount δ in a linear two dimensional geometry in Figure 2(e).

For the compression of an elastomer in a circular geometry, Figure 3, Equation 10 becomes

$$(2/3\ y_{max})\ (w)\ (\pi d) = \frac{\pi}{4}\ d^2\delta \tag{14}$$

or

$$y_{max} = (3/8)\ d\delta/w \tag{15}$$

and Equation 12 becomes

$$(1/2)\ \delta P\ \frac{\pi}{4}\ d^2 = (1/2)\ \left(8/3\ y_{max}{}^2\ (\pi d^2\,/\,4)\ G/w\right) \tag{16}$$

where the factor of 1/2 on the right side of Equation 16 relates, the average value of the strain energy to the maximum strain at the disk edge. It is deduced by a simple integration; it was 1/3 in Equation 12. We have replaced the plate area, Lh of Equation 12, with $\pi d^2/4$.

From Equations 15 and 16

$$P = (3/8)\ d^2\ \delta G/w^3 \tag{17}$$

This is the final result, relating the squeeze on the elastomer, δ, to the pressure applied, P, in the two dimensional circular geometry shown in Figure 3. The accuracy of final Equations 13 and 17 rely on the accuracy of the approximations made in deducing Equations 12 and 16 which are in turn based on Equation 9. These equations are probably quite accurate as long as the energy in the elastomer is primarily shear energy which means $w << d$, $y_{max} << d$, and maybe $y_{max} < w$.

2.4 Experimental Results

The Young's modulus, E, was measured for two elastomers* by cutting a 0.090" strip 6" long from a 1/16" sheet of the elastomer. It was stretched by a force, F, of 0.97 lb, resulting in a roughly 15% stretch for these elastomers. E was found from

$$E = (F/A)\ /\ (\Delta L/L) \tag{18}$$

*Viton, Elastomer Chemical Division, DuPont DeNemours and Company, Wilmington, Delaware where A is the cross sectional area of the elastomer $\Delta L/L$ is the fractional stretch. These measurements were complicated by the hysteric and time dependent behavior of the Viton. The modulus reported is characteristic of loading rather than unloading the elastomer. The figures indicate the E measured for the various elastomers.

The force required to compress the elastomers between two brass disks is shown in Figures 4, 5, and 6. Note the much larger deflections measured when the surface of the brass disk was smooth, having about a 6 finish. There was no lubricant put onto the surfaces; the elastomer was in the as-received condition. Note, also, with the smooth surface the large hysteresis. This is, of course, associated with the elastomer sliding against the brass as it extrudes during compression. When the force is later decreased sufficiently, it is able to slide back to its original condition. Presumably, the area inside the hysteresis loop appears primarily as frictional heating at the brass-elastomer faces. There was less hysteresis with the rough (photographic) finish of maybe 200 roughness.

The tests with the glued surface can be compared to the calculation of Equation 17. For the two tests with the glued elastomer we had $E = 805$ psi, using Equation 3 and $\nu = 1/2$ we have $G = 268$ psi. The resulting pressure, P, is then multiplied by the area of the disk to give the lines shown in Figures 5 and 6. In Figure 5 the calculated line agrees reasonably with the deflection versus force curve as the elastomer is stressed a small amount. In Figure 6 the measured deflection is about 30% less than calculated for small deflections.

2.5 Conclusions

We seem to have a reasonably accurate way of predicting the forces required to compress an elastomeric motion amplifier at low frequency. Now we must design an amplifier where the forces are small enough. If the forces are too large, more energy will go into the hysteresis of the elastomer than goes into compressing the gas, and a very inefficient compressor will result. Preliminary calculations have shown that this requires an elastomer with Shore A Durometer less than 30. We have obtained some low Durometer elastomers, and more are on order.

REFERENCES

1. Timoshenko, S. P. and Goodier, J. N. "Theory of Elasticity" McGraw Hill, N.Y., 1970.

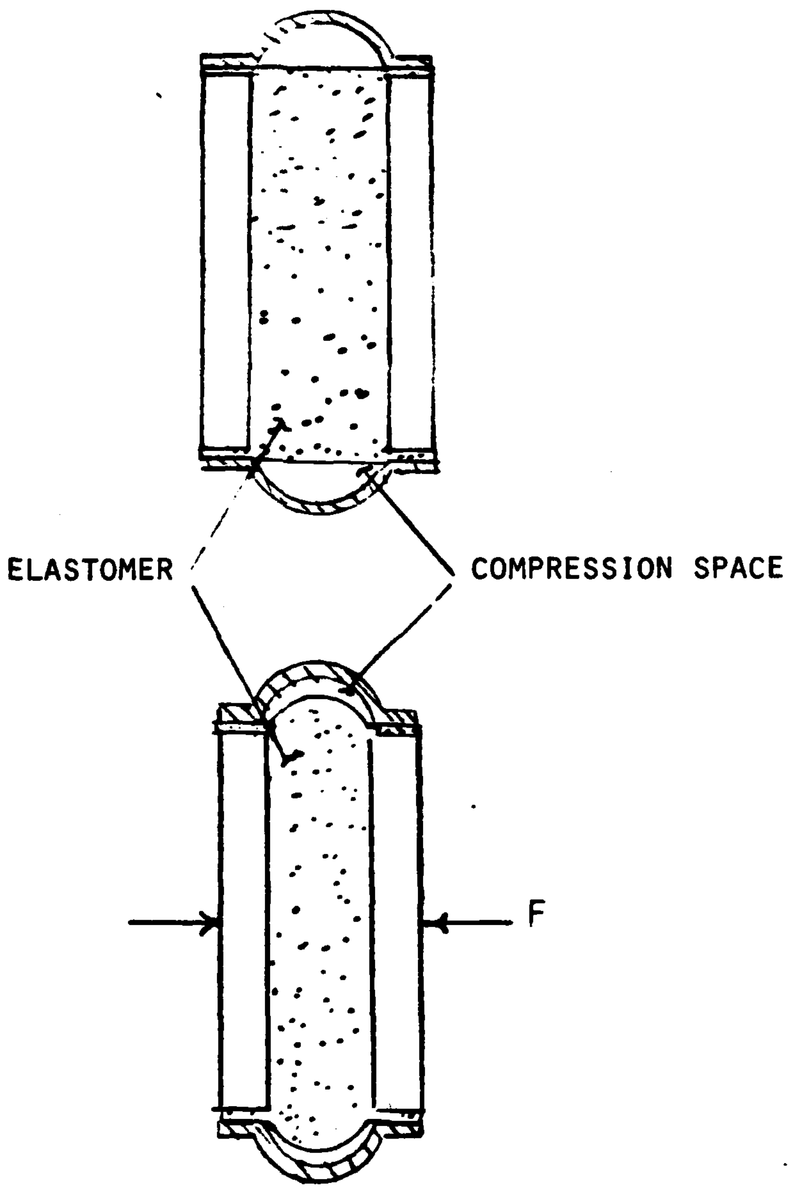


Figure 1. Principal of Elastomeric Motion Amplifier for Gas Compression

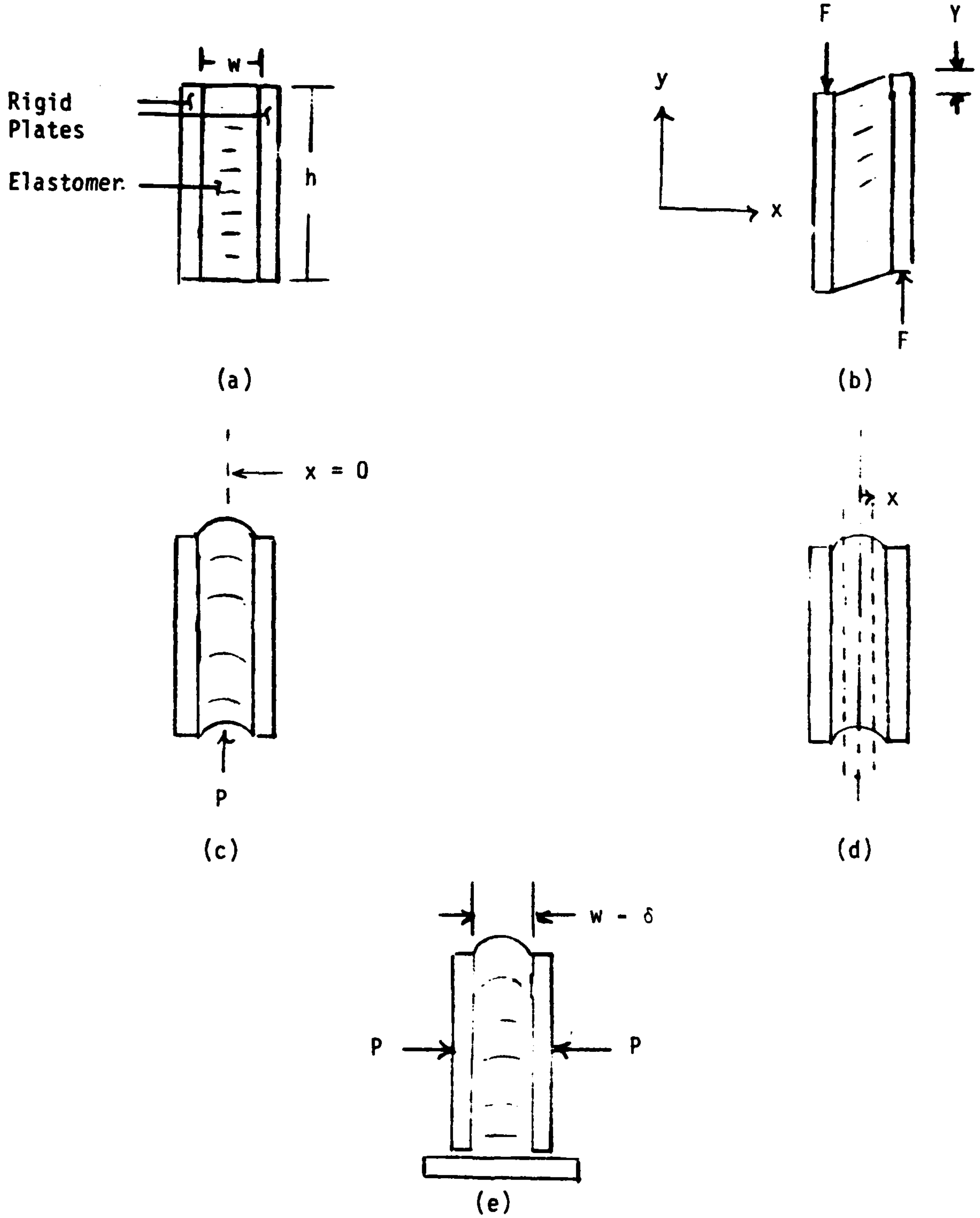


Figure 2. Elastomer Confined between Rectangular Plates Extending a Distance L into the Plane of the Paper

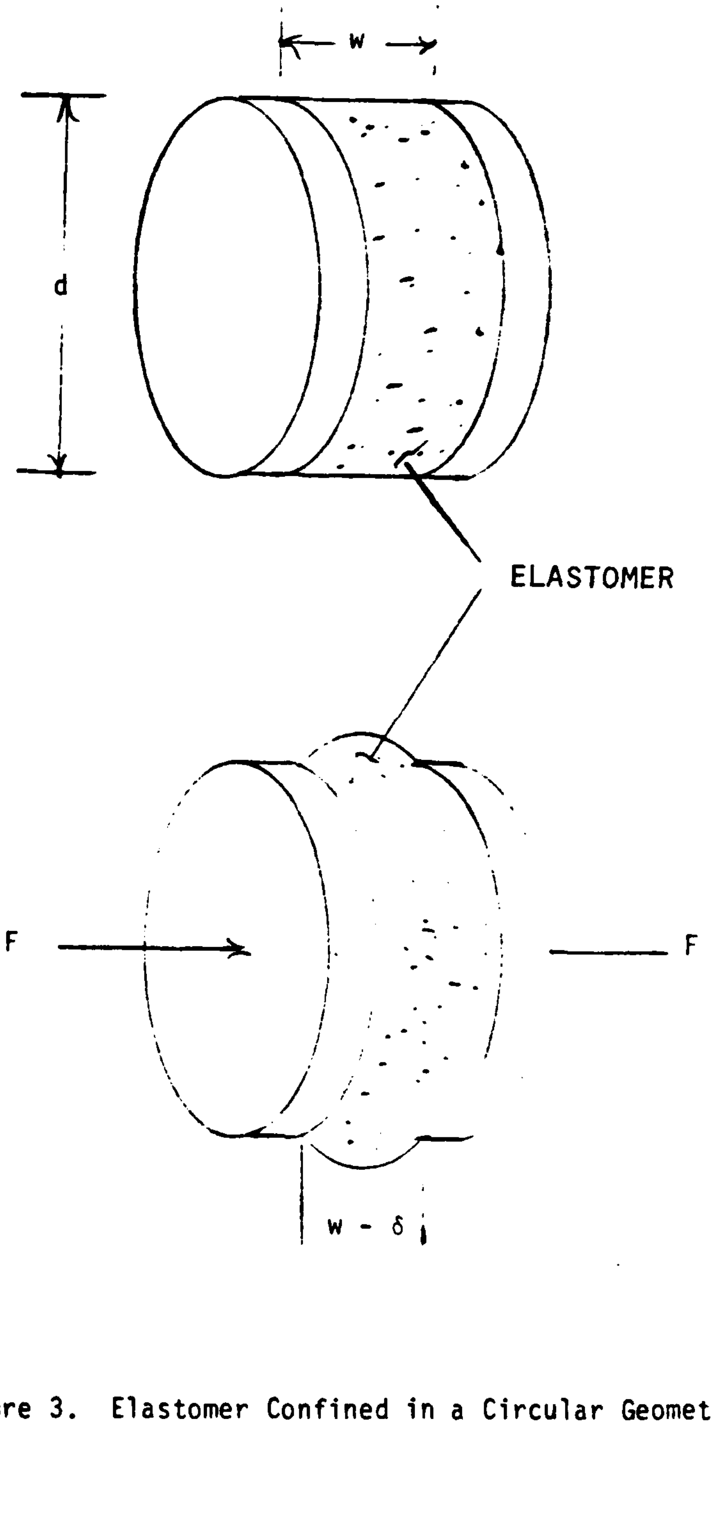


Figure 3. Elastomer Confined in a Circular Geometry

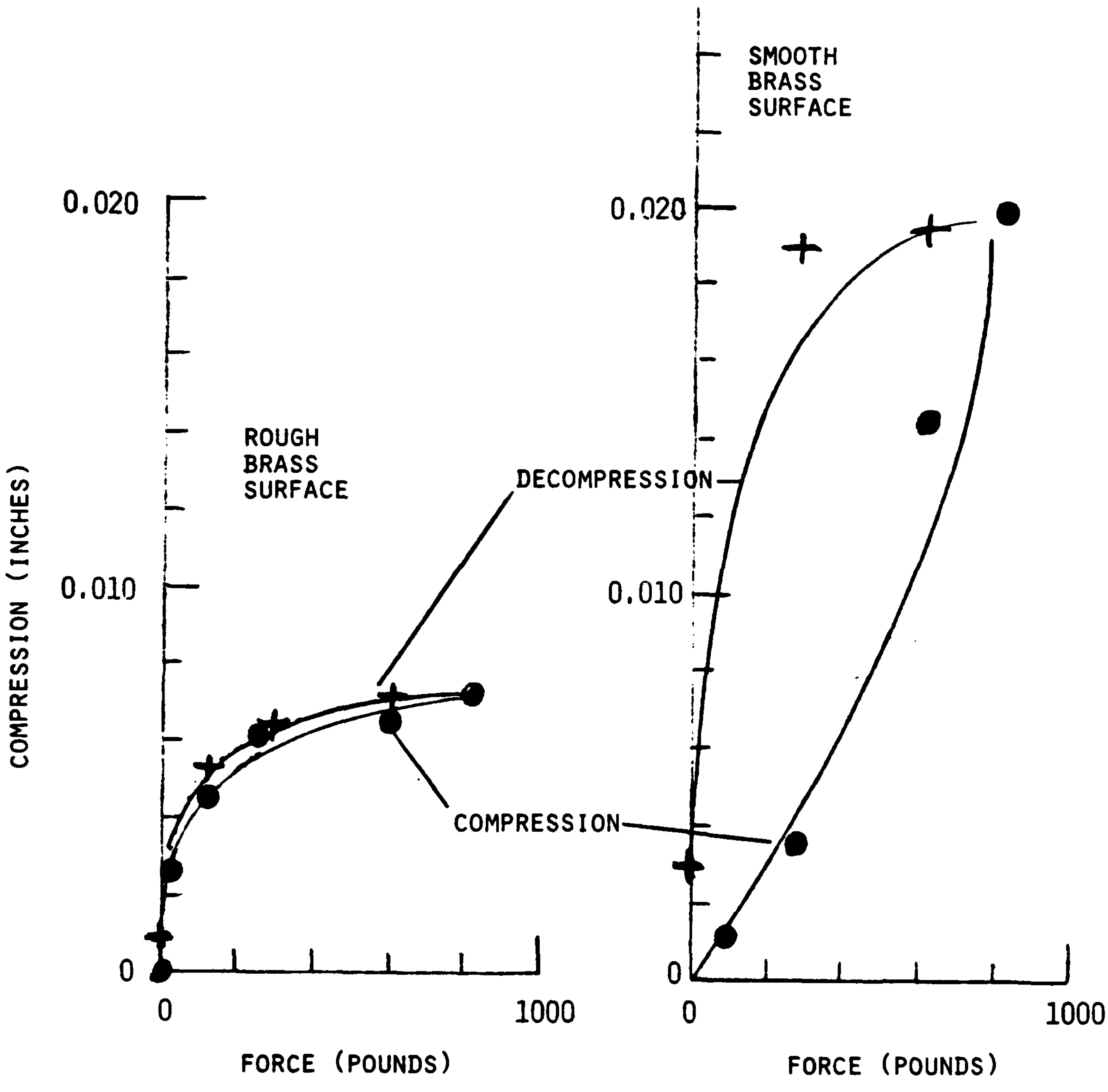


Figure 4. Force Required to Compress a 1/16" Thick Sheet of 80 Durometer Viton between Two 1" Brass Disks of Indicated Surface Finish

The Young's Modulus of the sheet was measured as 1190 psig.

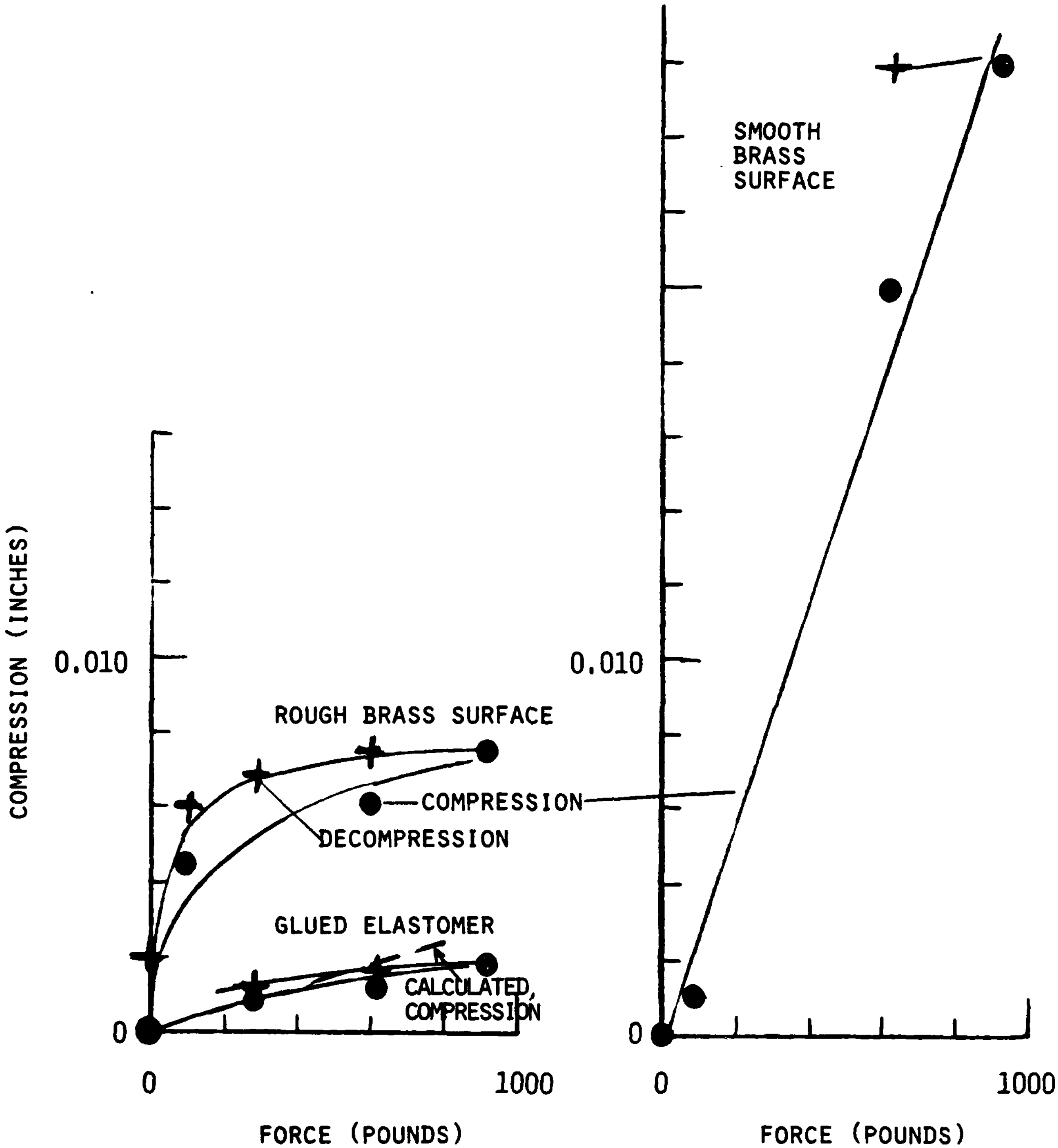


Figure 5. Force Required to Compress a 1/16" Thick Sheet of 73 Durometer Viton between Two 1" Brass Disks of Indicated Surface Finish When the Disk was Glued to Brass

The Young's modulus of the elastomer was measured as 805 psi.

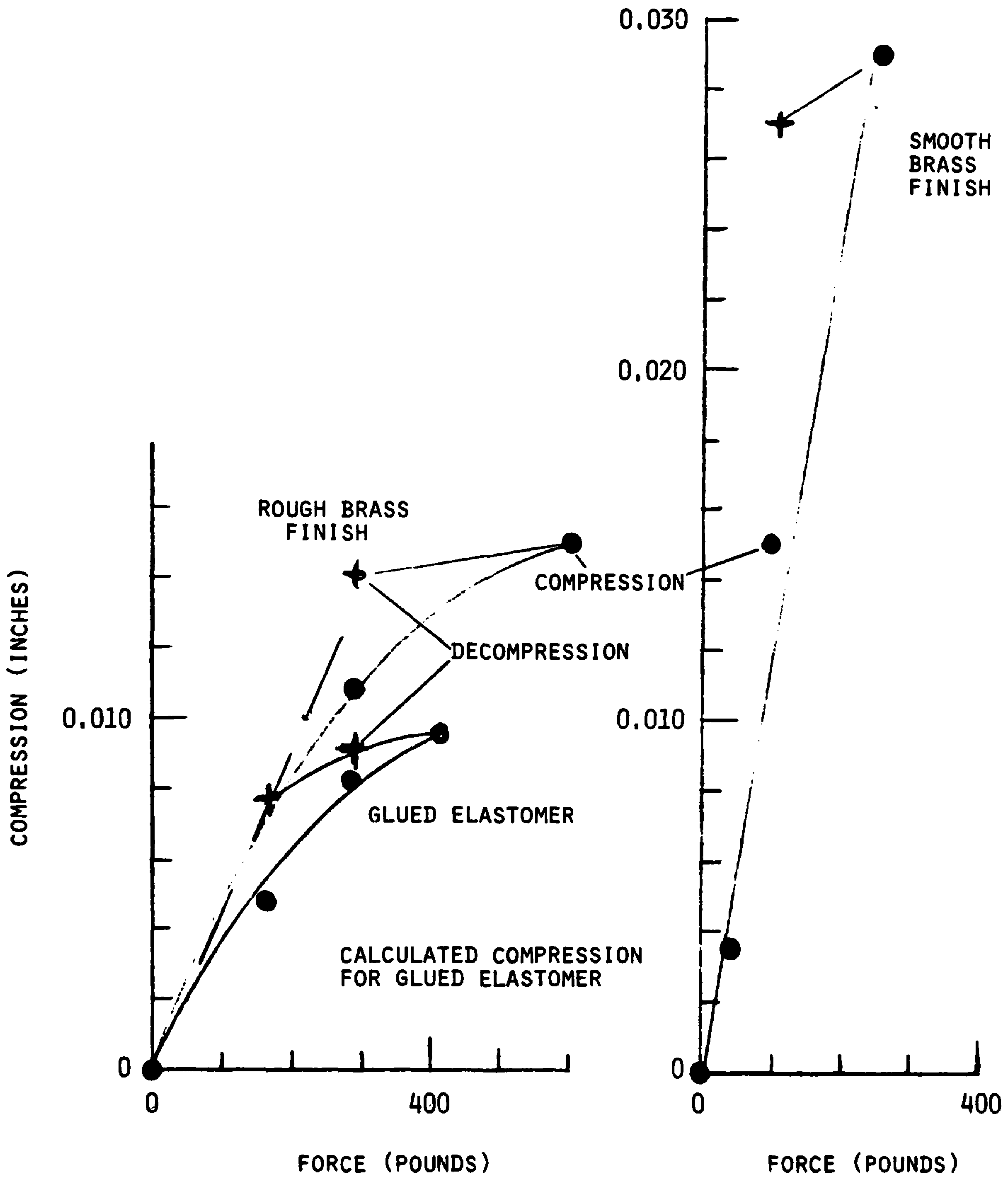
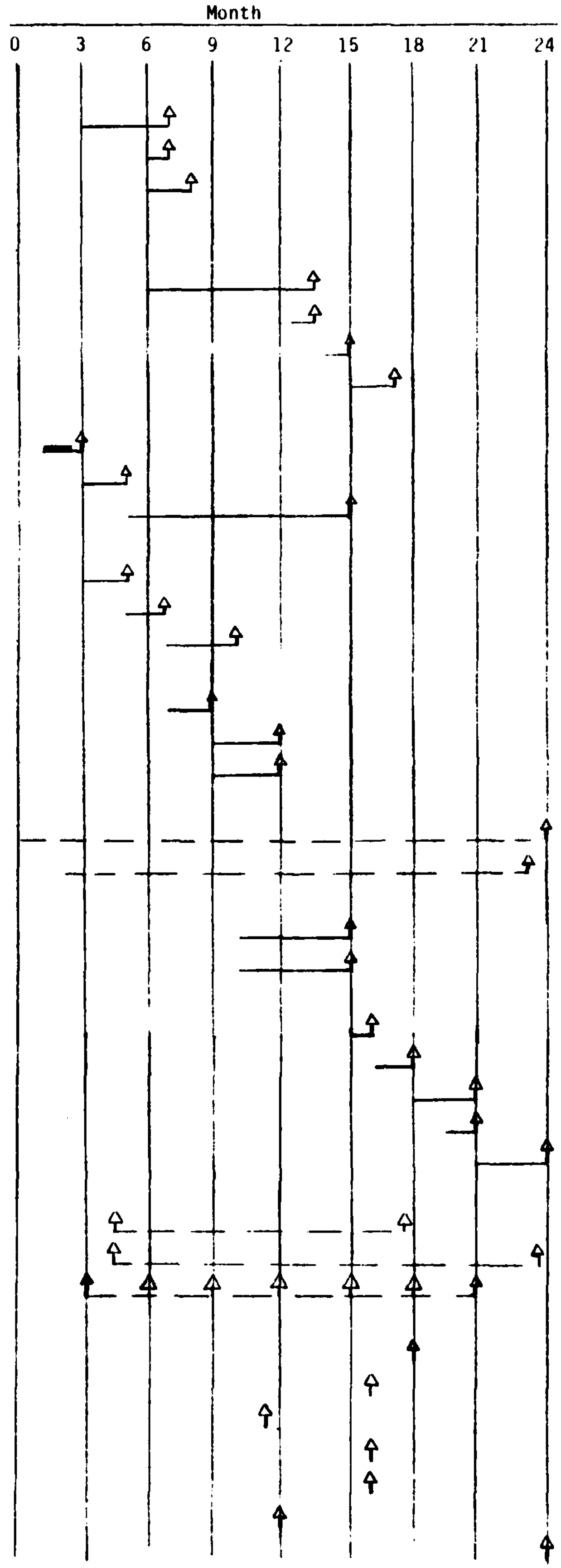


Figure 6. Same as Figure 5 except 1/2" Diameter Disks

DARPA TASK SCHEDULE - START 10/1/83

CONTRACT N00014-83-C-0394

	Task	By
1.1	Drivers for Prototype Units	
.1	Develop Type I Ceramics	PSU
.2	Define Design Parameter	PSU
.3	Specify Driver Design	CPI
.4	Fabricate 4 Sets, Deliver	PSU
1.2	Drivers for Final Unit	
.1	Research Type II Ceramics	PSU
.2	Define Design Parameters	PSU
.3	Specify Driver Design	CPI
.4	Fabricate 10 Sets, Deliver	PSU
2.1	One Cell Simulator	
.1	Design One Cell Simulator	APCI
.2	Fabricate One Cell Simulator	APCI
.3	Test Materials	APCI
2.2	Three Cell Simulator	
.1	Design 3 Cell Simulator	CPI
.2	Fabricate 3 Cell Simulator	CPI
.3	Test Pumping Action	CPI
3.	Driver Electronics	
.1	Specify Driver Elec. Charter.	CPI
.2	Design & Fab. Driver Elec./3 Cell	CPI
.3	" " " " /1 Cell	APCI
4.1	System Analysis	
.1	Elastomer Stress, System Design	APCI
.2	Compressor/Driver Analysis	CPI
4.2	Prototype Compressors	
.1	Design, Fab.&Test 1 Cell Proto.	APCI
.2	" " " 3 Cell Proto.	CPI
4.3	Final Compressor	
.1	Design Multicell Compressor	APCI
.2	Fabricate Multicell Compressor	APCI
.3	Test Multicell Compressor	APCI
4.4	Design, Fab. & Test Cryostat	APCI
4.5	Test Final System	APCI
5.1	Status Reports	
.1	Subcontractor Reports, Mo.-15th	PSU
.2	" " " "	CPI
.3	Report to DARPA, Quarterly-30th	APCI
5.2	Interim Technical Reports	
.1	Driver Research	PSU
.2	One Cell Simulator	APCI
.3	Three Cell Simulator	CPI
.4	One Cell Prototype	APCI
.5	Three Cell Prototype	CPI
.6	Mid-Term	APCI
5.3	Final Report	APCI



Air Products

DARPA CONTRACT NO. N00014-83-C-0394

STATEMENT OF WORK

Work done under this contract is to be in general accordance with Section 5 of the proposal titled "Development of a Miniature, Solid-State Gas Compressor." This statement of work elaborates on Section 5 of the proposal and will be followed in carrying out the contract.

	Statement of Work	Task
1.	Driver Ceramics	
1.1	Drivers for Prototype Units	
1.1.1	Fabricate several multilayer ceramic drivers from PMT-PT materials which have been studied previously and are known to have a σ value of about 0.09%.	PSU
1.1.2	Study sample PMT-PT drivers to measure the characteristics that are needed to specify the design of prototype drivers. Send information to CPI and APCI.	PSU
1.1.3	Prepare a specification for the prototype drivers, e.g., geometry, orientation of layers, driving voltage. Send specifications to PSU and APCI.	CPI
1.1.4	Fabricate four (4) pairs of prototype drivers. Deliver three pairs to CPI and 1 pair to APCI.	PSU
1.2	Drivers for final unit	
1.2.1	Research fabrication and design characteristics of materials having a σ value of about 0.2%. Materials to include "ultrasoft" PLZT type and "fuzzy cubic" PZ-PT-PMN type.	PSU
1.2.2	Select most promising candidate material and provide date to CPI and APCI which is needed to design drivers for final unit.	PSU
1.2.3	Prepare a specification for the final drivers and send to CPI and APCI.	CPI
1.2.4	Fabricate ten (10) pairs of drivers for the final unit. Send them to APCI.	CPI
2.	Mechanical Simulator	
2.1	One Cell Simulator	
2.1.1	Search elastomer literature in order to select most promising candidate materials. Define material properties that need to be studied experimentally.	APCI

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Statement of Work		Task
2.1.2	Design a mechanical simulator primarily for the purpose of evaluating elastomer properties and secondarily to explore compressor configurations. Design a single cell unit having inlet and discharge valves.	APCI
3.1.3	Fabricate a mechanical simulator and a number of elastomer samples.	APCI
2.1.4	Test material samples and evaluate performance characteristics of the single cell compressor.	APCI
2.2	Three Cell Simulator	
2.2.1	Design a three cell mechanical simulator primarily for the purpose of studying compressor performance including valving effects. Use polyurethane elastomer 70 durometer, because it is known to be a prime candidate material.	CPI
2.2.2	Fabricate three cell simulator and a number of different elastomer geometries.	CPI
2.2.3	Measure performance characteristics of three cell simulator.	CPI
3.	Driver Electronics	
3.1	Specify characteristics of driver electronics which are required to optimize efficiency of the driver and compressor consistent with driver and compressor life.	CPI
3.2	Design and fabricate driver electronics for one cell prototype	APCI
3.3	Design and fabricate driver electronics for multicell prototype and final ten cell unit.	CPI
4.	Compressor Development	
4.1	System Analysis	
4.1.1	Carry out analytical analysis of elastomer stress-strain relations for several different geometries and different operating modes. Analyze other system design parameters as required.	APCI
4.1.2	Analyze compressor/driver characteristics to optimize force displacement time relations for each compression cell.	CPI
4.2	Prototype Compressors	
4.2.1	Design, fabricate, and test a one cell prototype compressor with a pair of prototype ceramic drivers and inlet and outlet valves.	APCI

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	Statement of Work	Task
4.2.2	Design, fabricate, and test a three cell prototype compressor with three pairs of prototype ceramic drivers.	CPI
4.3	Final Compressor	
4.3.1	Design and fabricate final multicell compressor using final ceramic driver sets and ten cell electronic drive.	APCI
4.3.2	Test final multicell compressor	APCI
4.4	Design, fabricate, and test a cryostat which can be mated to the final compressor using refrigerant 12 (Freon 12)	APCI
4.5	Test final system, ten cell compressor, and cryostat	APCI

APCI - Air Products and Chemicals, Inc.

CPI - CeramPhysics, Inc.

PSU - Pennsylvania State University

R. C. Longsworth
October 1983